

# Impact of Introducing Longer and Heavier Vehicles on Regional Consumer Price Index and Spanish Road Freight Transport System

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This paper applies an integrated modeling approach to the case of Spain; the approach is based on a random utility-based multiregional input-output model and a road transport network model for assessing the effect of introducing longer and heavier vehicles (LHVs) on the regional consumer price index (CPI) and on the transportation system. The approach strongly supports the concept that changes in transport costs derived from the LHV allowance as well as the economic structure of regions have direct and indirect effects on the economy and on the transportation system. Results show that the introduction of LHVs might reduce prices paid by consumers for a representative basket of goods and services in the regions of Spain and would also lead to a reduction in the regional CPI. In addition, the magnitude and extent of changes in the transportation system are estimated by using the commodity-based structure of the approach to identify the effect of traffic changes on traffic flows and on pollutant emissions over the whole network.

Transportation costs depend on a mix of spatial interactions and economic circumstances that are important for trade. Specifically, Hummels assigns three levels of importance to transportation costs: (a) importance relative to the value of the goods being moved; (b) importance relative to other known barriers to trade, such as tariffs; and (c) importance in regard to the extent to which such costs can change relative prices (1). For that reason, variables such as distance, geography, and transport technology will play a crucial role in affecting relative prices, which will shape the volume and nature of trade patterns between regions.

For these reasons, transportation costs have been studied in the literature mainly from two perspectives: (a) first, as an essential constituent for promoting trade patterns and economic growth and (b) second, as a cost function for the allocation of fixed and variable costs. Previous research in these fields has been directed at addressing multilateral trade and cost estimating functions [for details, see Hummels (1), Combes and Lafourcade, (2) and Janic (3)]. As a result,

the estimation of transportation costs and effects from transportation policies are well documented. Impact assessment has shown a strong linkage between transportation costs and economic development, but a direct measurement (using, for example, the consumer price index (CPI) of how changes in the weighted average for the price of a basket of consumer goods and services reflect the transportation policies by region is still scarce [see, e.g., Banister and Berechman (4) and Rephann (5)].

The current research aims at filling that gap by addressing the effect of transport policies on transportation costs, commodity prices, CPI, and changes in the transportation system performance. For that purpose, an integrated model approach including a random utility-based multiregional input-output (RUBMIO) model and a road transport network model has been applied to study the effect of introducing longer and heavier vehicles (LHVs) in a selected road transport network of Spain [9,799 km (6,089 mi) in length]. Results come from a comparison between the base case scenario and the case study.

This paper is organized as follows. A brief overview of the research is first provided. Next, the methodology proposed and its limitations are discussed. A detailed description of the case study is then offered, followed by an analysis of results in regard to regional CPI changes and the transportation system. Finally, the most relevant conclusions and suggestions about the implementation of policies as well as possible future developments are presented.

## METHODOLOGY FOR ESTIMATING IMPACTS

### Consumer Price Index

The CPI is used to measure changes in the price level of a basket of consumer goods and services purchased by households. The CPI is one of the most closely watched compilations of statistical data calculated and published worldwide. The CPI is constructed by using prices of a basket of goods and services and weighting data as expressed in the following equation:

$$CPI_i = \frac{\sum_{j=1}^n \text{price}_j \times \text{weight}_j}{\sum_{j=1}^n \text{weight}_j} \quad (1)$$

where  $CPI_i$  is a weighted summation of multiple  $n$  goods or services of a market basket for the year  $i$ ; and  $\text{price}_j$  and  $\text{weight}_j$  are the price

of goods or services and the weights for each category  $j$  of goods or services, respectively, that make up the market basket. Estimating the CPI is complex because the estimate must define the commodities and services that are most useful to be included and measured, how to measure them, how to collect data on them and over what span of time and at what interval, where and when to collect, and how to aggregate them in one or several overall statistical summaries (6).

Although the CPI is computed monthly or quarterly in some countries, a 12-month period is most commonly used. In addition, the calculation of the CPI is very important for society since the CPI is used for a multiplicity of purposes, including its importance in the calculation of (a) an employee compensation index, (b) a cost of living index, (c) a consumption deflator, and (d) the overall rate of inflation (7).

### Integrated Approach for Assessing Economic and Transportation Impacts of Transport Policies

The economic impacts of transport policies have usually been analyzed through standard neoclassical or Keynesian comprehensive trade models focused on the relationship between labor time, capital goods, output, and investment rather than on the study of the location, distribution, and spatial organization of economic activities [see, e.g., Aschauer (8) and Munnell (9)]. Other researchers have pointed to strong evidence for the importance of geography in shaping economic interactions, competition, agglomeration, and labor market effects—known as wider economic benefits—to the assessment of transport policies (10–12).

In that regard, the members of the Organisation for Economic Co-operation and Development have acknowledged the mesoeconomic level in which the economic system is described as an intermediate level in which prices are determined and agents exchange goods, services, assets, and labor, taking into account regional level disaggregation (13). In fact, at this level, economic analyses estimate the benefits of transport policies in the context of wider economic benefits, economic activity, and location impacts.

There are several ways of approaching economic impacts at the mesoeconomic level. Some of the available models have been directed toward forecasting, policy simulation, and project evaluation [for more details see Gkritza et al. (14), Kim et al. (15), and Weisbrod and Beckwith (16)]. All of these practical models have been developed on the basis of gravity model simulations, multiregional input-output (MRIO) analysis, systems dynamics models, or spatial computable general equilibrium models. These models address interactions between spatial economics and transport systems, including the technical structure of the industry and the requirements for trade (17, 18). The models have rarely been used in connection with the study of a transportation network.

This modeling approach fits within the mesoeconomic framework considering trade flow patterns between regions involving transportation costs and commodity prices through two connected models: the RUBMRIO approach (Figure 1a) and the road transport network model (Figure 1b).

The RUBMRIO models simulate trade between regions (exports to other regions and imports from other regions) depending on transportation costs in the road network.

Moreover, the introduction of LHV has traditionally been assessed from the microeconomic point of view. These desk-based studies have focused on analyzing the economic efficiency of implementing LHVs by using cost-benefit analysis methodologies, taking into account different variables, such as infrastructure costs, safety, energy

consumption, and traffic safety. Few models linking demand models and regional economic models for LHVs are available worldwide [for details, see De Ceuster et al. (19), K+P Transport Consultants and ISI Fraunhofer (20), and Doll et al. (21)]. For that reason the integrated approach is a significant new way to more fully assess the impact of transportation policies.

However, that approach has inherent and inevitable limitations. The first set of limitations stems from the incomplete availability of input-output (IO) data concerning the more detailed representation of territorial regions as well as information from other countries. The second set of limitations comes from the IO methodology, since it does not permit one to (a) answer questions concerning matters such as innovation, technological progress, ownership structures, and other economic factors of industries; (b) offer a snapshot of the effects on the economy at a particular time; (c) combine several transport scenarios simultaneously; (d) offer models of passenger transport and logistic facilities to handle freight for every sector and origin-destination (O-D) pair; and (e) derive transportation costs from confidential business data or negotiations between carriers.

### RUBMRIO Model

An MRIO table displays the economic relationships between different sectors of production and regions of a country. The MRIO table would characterize the flow of goods by using IO coefficients, demand functions for intersectoral flows, or RUBMRIOs for their spatial distribution, taking into account trade coefficients (22). Trade coefficients simulate the choice of supply region since they show the probability that a product of sector  $m$  consumed in region  $j$  would have been transported from production region  $i$ .

This approach sets the linkages of interindustry sales and purchases between regions in a given country by using a commodity-based structure. Consequently, the RUBMRIO is able to show shifts between industries and sectors and regions supporting generative, redistributive, substitutability, and complementarity effects through trade patterns.

RUBMRIO analysis has been performed on well-known land use models involving spatial economics (23). Existing RUBMRIO applications of transport cover different ex ante topics such as construction of transportation corridors, changes in travel times, transport investments, operational cost variations, fuel taxes, road charging, trade pattern changes, and regional transport conditions [for more details, see Du and Kockelman (24), Cascetta et al. (25), Huang and Kockelman (26), Guzman and Vassallo (27), and Zhao and Kockelman (28)]. Although these applications have identified important indirect effects of transport policies at the regional level on various macroeconomic aggregate indicators, most of these applications did not calculate direct effects on the transportation system (e.g., congestion reduction, time savings, traffic deviation, pollution, and reduction of emissions). In this research a transport network model is used to take these effects into account.

The price at origin has been determined through an iterative single fixed-point algorithm that defines a sole spatial equilibrium solution [assumptions about the procedure are extensively described in Zhao and Kockelman (28)]. Cascetta et al. have proposed the RUBMRIO model solution through a double fixed-point formulation by considering the introduction of a new feedback in the model (25). However, the conditions for attaining a solution taking into account the uniqueness of the double fixed-point approach are still under development.

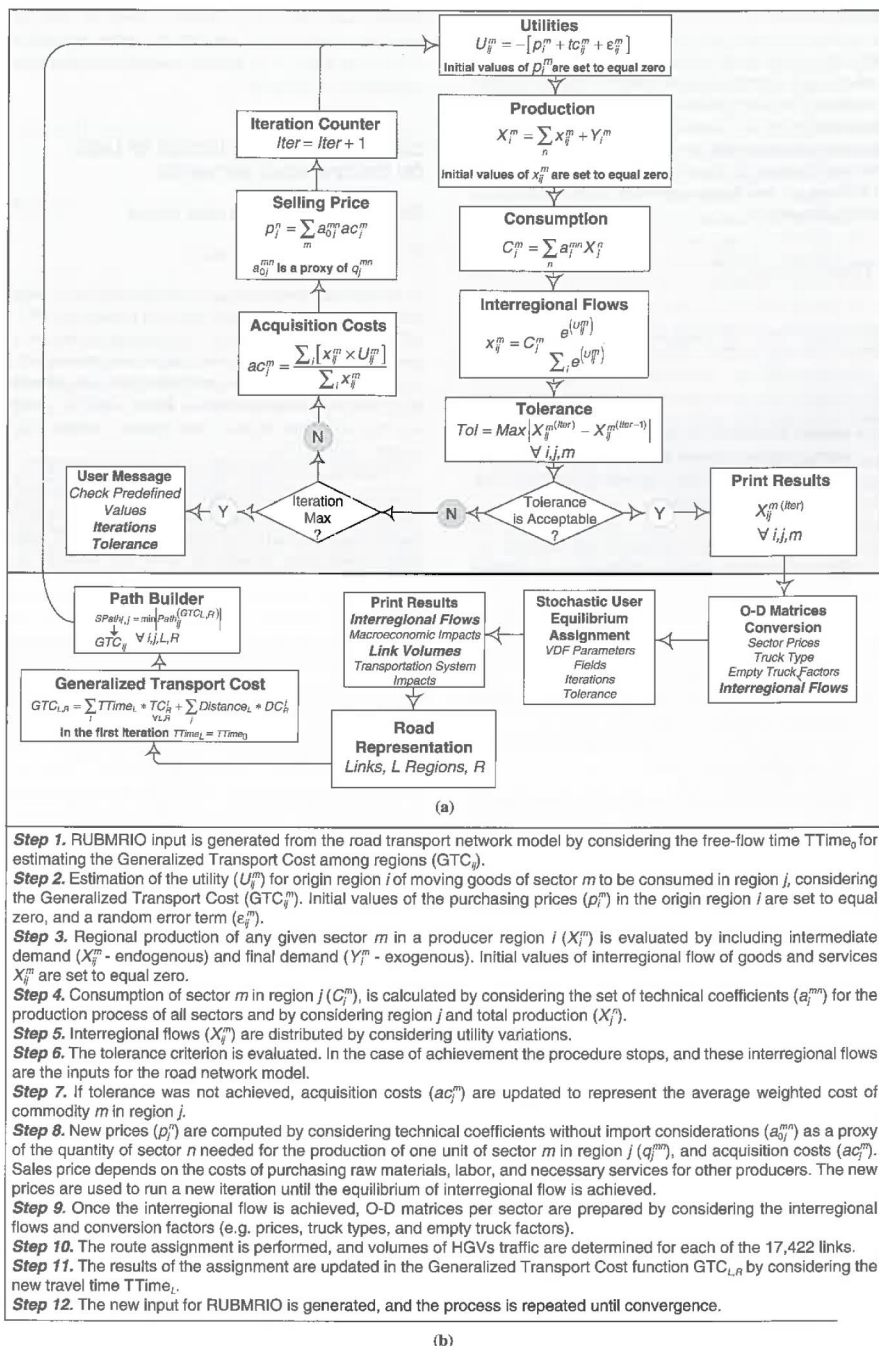


FIGURE 1 Integrated approach for macroeconomic assessment: (a) RUBMARIO algorithm and (b) road transport network model.

## Road Network Model

The road network is made up of a set of nodes and links including attributes such as length, travel time, speed, number of lanes, and traffic flow restrictions. The model has two main purposes. First, it provides an assignment procedure for predicting the traveler's choice of routes in the road transport network. A volume–delay function (VDF) is considered (see Equation 2). Second, the model determines possible routes between any two locations through a cost minimization criterion given by Equation 3.

$$TTime_L = TTime_o \times \left[ 1 + \alpha \left( \frac{v}{c} \right)^\beta \right] \quad (2)$$

$$GTC_{L,R} = \sum_i TTime_L * TC_R^i + \sum_j distance_L * DC_R^j \quad (3)$$

where

$TTime_L$  = average travel time for vehicle on link  $L$  (min), indicating expected amount of time spent by vehicles to traverse a certain defined segment of highway when trips are added up in link;

$TTime_o$  = free-flow travel time;

$v$  = traffic volume of heavy goods vehicles (HGVs);

$c$  = practical capacity, which is reduced by the amount of roadway capacity that is utilized by the preload volumes—corresponding to trips performed by car and bus;

$\alpha$  and  $\beta$  = Bureau of Public Roads parameters defined by link type (usually 0.15 and 4, correspondingly);

$GTC_{L,R}$  = the generalized transport cost (GTC) in each link  $L$  belonging to a specific region  $R$ ;

$TC_R^i$  = time costs per minute (e.g., labor, financing, insurance, tax, and other, indirect costs);

$distance_L$  = length of link (km); and

$DC_R^j$  = distance costs (€/km) (e.g., fuel, tolls, accommodation, allowances, tires, maintenance, and repairing costs).

The parameters  $\alpha$  and  $\beta$  facilitate the adoption of different functions for different kinds of links and for each class of traffic. The practical road capacity  $c$  is generally used to show the maximum possible flow of vehicles that can be allowed in a road section per time period (usually 1 h). Most travel demand models use time-of-day factors to distribute trips according to specific time periods to determine traffic behavior at the peak period.

## Model Integration and Solution Procedure

From the road transport network, the values of  $GTC_{ij}$  among regions are calculated by considering  $TTime_o$  in Equation 3. ( $TTime_o$ , a proxy value, was used to generate the RUBMRIO input in the first iteration.) These values are used to generate the RUBMRIO, which is solved iteratively through the single fixed-point algorithm implemented through a macro program based on Visual Basic for Applications in Excel (see Figure 1a) until consecutive trade flows stabilize with an error lower than 1% defined by the tolerance criterion. After this, O-D matrices are generated by transforming monetary values of the MRIO table into vehicles. These O-D matrices corresponding to each economic sector are assigned to the road transport network to determine traffic volumes in the links, which enable one to update

costs according to the new  $TTime_L$  as shown in Figure 1b. The integrated approach is rerun, similarly as in other research works (26), with the updated  $GTC_{L,R}$  through an iterative feedback process until convergence is achieved.

## CASE STUDY: INTRODUCTION OF LHV'S ON SPAIN'S ROAD NETWORK

### Development of Integrated Model

#### RUBMRIO Model Estimation

To construct the model for Spain the existing interregional IO table developed by the DESTINO research project for 2007 was used (29). To build up an MRIO, a simplifying procedure was developed to aggregate sectors identified as freight transport–intensive sectors (see Table 1) and non-freight transport–intensive sectors (e.g., trade and repair of vehicles, finance and real estate, tourism, and education) and to discard multisector relationships between sectors ( $m$  to  $n$ ) (30).

Concerning the utility function, a nested logit (NL) model was adopted representing the choice of regions in two relevant nests (within region and outside region) and four relevant alternatives (same, close, near, and far) as presented in Equation 4. Although some utility models have included rail in the NL structure, that was not

TABLE 1 IO Economic Sectors and Estimated Parameters for NL Model

Freight Transport–Intensive Sector	$\theta^n$	$\lambda^n$	McFadden's Pseudo- $R^2$ ( $p^2$ )
1. Agriculture, fishing, wood, and cork	−0.00370* (−1.791) <sup>a</sup>	0.602	.151
2. Food and kindred products	−0.00221 (−1.618) <sup>a</sup>	0.398	.174
3. Nonmetal minerals and kindred products	−0.00310** (−2.469) <sup>a</sup>	1.212	.174
4. Energy, petroleum, and petroleum products	−0.00359* (−1.662) <sup>a</sup>	0.286	.101
5. Mining	−0.00292** (−2.393) <sup>a</sup>	0.999	.328
6. Metal minerals and kindred products	−0.00262* (−1.942) <sup>a</sup>	0.759	.123
7. Construction	−0.00363** (−2.508) <sup>a</sup>	1.730	.365
8. Chemical and allied products, paper, edition and kindred products, rubber materials	−0.00186* (−1.726) <sup>a</sup>	0.534	.166
9. Textiles, clothing, leather and shoes, industrial machinery and equipment, electric and electronic equipment, transportation equipment, and other manufacturing industries	−0.00252* (−1.68) <sup>a</sup>	0.417	.144

NOTE:  $\theta^n$  and  $\lambda^n$  = logit model parameter estimates obtained by using NLOGIT with maximum likelihood methods.

<sup>a</sup>The value in parentheses is the Wald statistic.

<sup>b</sup>Also called the likelihood ratio index.

\* $p < 0.10$ ; \*\* $p < 0.05$ .

done here because rail's market share is negligible in Spain (25, 26). The NL structure was a way of overcoming problems detected in the single-level multinomial logit formulation.

$$U_{ij}^m = -p_i^m + \lambda^m \ln \left[ \sum_R \exp(U_{ij,R}^m) \right] \quad (4)$$

$$U_{ij,R}^m = \theta^m \text{GTC}_{ij,R}^m \quad (5)$$

where

$U_{ij}^m$  = utility for region  $j$  of acquiring commodity  $m$  in region  $i$  (systematic utility of lower nest  $U_{ij,R}^m$  is defined in Equation 5),

$p_i^m$  = price of goods and services of sector  $m$  in region  $i$ ;

$\lambda^m$  and  $\theta^m$  = logit model parameters, and

$\text{GTC}_{ij,R}^m$  = GTC of sector  $m$  goods from production or origin region  $i$  to consumer region  $j$ .

Total GTC between production and consumer regions was incorporated to avoid possible multicollinearity problems.

To calculate transport costs inside the same region (i.e.,  $i = j$ ), an average cost value was determined from the capital of the region to provinces of that same region by using the road transport network. Regions outside continental Spain were linked to the continental transport network by using fictitious links and attributing a larger share of the total costs to fixed costs in the transport network. This calculation assumes that transport costs increase with distance. The resulting  $\text{GTC}_{ij,R}^m$  combinations are computed through the road network model as it is described in detail in the following section.

The parameter estimates of the NL utility model (shown in Table 1) were obtained by using NLOGIT with the maximum likelihood method. The estimated coefficients have the expected signs because costs have a negative effect on utility. Moreover, the Wald statistic (values in parentheses) rejects the null hypothesis that the coefficient is zero with a 90% level of confidence;  $p$ -values for each parameter are reported. Also, it is convenient to measure goodness of fit analogous to those measures in linear statistical models. Indeed, the likelihood ratio index—McFadden pseudo- $R^2$  ( $p^2$ )—provides a convenient basis for comparing different models when more than one alternative is estimated. Pseudo- $R^2$  values between .2 and .4 are fairly good, according to McFadden (31).

Low values in those two tests could be explained by the lack of sufficient data at this point (32). The indication is that more data about flows of goods would be required to obtain more accurate results, but unfortunately these data are not available for Spain.

### Road Network Model

In 2007 Spain had more than 13,000 km (8,078 mi) of modern high-capacity roads made up of tolled highways, free highways, and multi-lane national roads (see Figure 2a). With regard to freight transport in Spain, official statistics state that 1,567 million tonnes were transported by road in 2010 (97% domestic and 3% international) (33). By contrast, the rail freight transport amounted to only 21.4 million tonnes (34). These figures clearly show that in Spain road transportation still retains its position as the dominant mode for freight.

The road network model was built with TransCAD software. Capacity (vehicles per hour) and speed targets are defined by the gov-

ernment for each classification of roads by function. These values have been included as inputs for each link of the road network. In addition, the greater the slope of a road the greater the reduction in the speed and capacity of the traffic on that road. Therefore, speed and capacity have been reduced by considering factors reflecting the slope of the road. The traffic count data taken from the Ministerio de Fomento were used; they were sorted by type of vehicle and included for each link to validate the base-case year assignment model (35). It had to be considered that in the model, truck traffic, which is affected by the introduction of LHV, and cars and buses use the same road network. Therefore these traffic flows were treated as a preload volume, because they are not being included in the integrated modeling approach.

Conversion factors from the RUBMRIO were applied so as to convert the measurement of the commodity trade in the transportation system from monetary units (euros) to tonnes, and from tonnes to trucks per year, and finally, to trucks per day. This conversion used an average price per tonne for a specific commodity (€/tonne), the HGVs configuration of each sector, and a factor reflecting the percentage of trips of empty trucks. This procedure enables one to obtain O-D matrices per sector.

The percentage of empty HGVs was adopted from the Ministry of Transportation of Spain, considering pickup and delivery truck operations in both directions of O-D pairs as a proxy since detailed information required to build up an empty trip model for Spain was not available (30). Additional information concerning external trips (imports and exports to and from other peripheral countries such as Portugal and elsewhere in Europe) was also incorporated as it was not included in the RUBMRIO (36).

A multimodal multiclass stochastic user equilibrium assignment procedure was conducted to assign the HGV traffic of the resulting O-D matrices as user classes and considering VDF functions for each functional classification class through TransCAD. These functions incorporated individual variations of generalized cost perceptions. A time period of 24 h (1 day) was adopted since detailed information about time periods was not available, taking into account that daily capacity is calculated by multiplying the hourly capacity by a daily expansion factor.

The process of validation was conducted on the basis of comparisons between predicted and observed flows in all links of the base-case scenario to determine whether the assignment model is loading HGV trips for each functional class in a reasonable way. The VDF parameters and daily expansion factor changes were introduced in an iterative process intended to minimize deviations between assigned and observed traffic flows. The validation results depicted in Table 2 show how recommended targets given in the guide were met for each functional classification class (37). In addition, the model validation in each link was checked considering the guide (38). Percentages of deviation for daily volumes were calculated for individual links. The results show that 10% of the 3,874 links exceed the target values recommended in the guide. According to these results, the application of the model for the introduction of LHVs should produce reasonable results.

### LHV Scenario Description

It is assumed that the introduction of LHVs will affect only the road mode since freight by rail in Spain is already so very low (only 2%) and there are no inland waterways. For this reason, no effects in the modal split were considered. The most suitable LHV configuration for Spain is made up of a tractor, semitrailer, and center-axle trailer



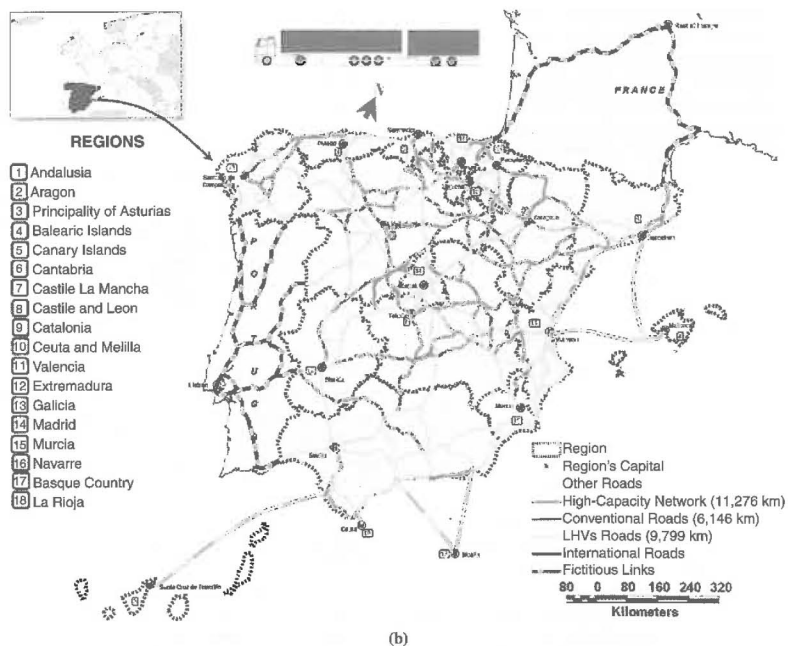


FIGURE 2 Spanish road transport network (2007): (a) base case and (b) LHVs scenarios.

TABLE 2 Road Transport Network Model Validation by Functional Classification Class

Functional Classification Class	Number of Links (km)	Average Traffic Count Data	Average Error	Error (%)	RMSE (%)	Recommended % RMSE <sup>a</sup>
1. Talled highways	578 (2,703)	5,576	-111.88	-3.65	29.92	43
2. Free highways	1,776 (8,122)	8,562	129.39	3.57	21.91	37
3. National road system	1,520 (6,597)	3,547	183.50	19.86	45.55	51
All	3,874 (17,422)	8,523	114.62	4.62	27.95	37

NOTE: RMSE = root mean square error.

<sup>a</sup>Recommended %RMSE targets were calculated for the average traffic count data in accordance with the FHWA guide (37).

(30). The LHV scenario was developed by considering (a) the road network ready to handle LHVs, (b) the distance over which goods are transported, (c) the characteristics of commodities transported, (d) the potential market that might be relocated away from the existing ones, and (e) the expected cost reduction factor of LHVs compared with that of HGVs.

The selected road network adopted for the LHVs scenario (see Figure 2b) is made up of high-capacity roads connecting the capitals of the regions. High-capacity roads are suitable to handle LHVs, whereas national roads do not. The length of the road network where LHVs could be introduced is 9,799 km (6,089 mi). Intra-regional O-D pairs have been excluded because LHVs are favorable mostly for longer distances (19, 20).

Table 3 summarizes the migration factors by commodity in the following way. First, loads transferred from HGVs to LHVs were

estimated on the basis of other countries and their physical characteristics, such as the weight, volume, or both for each commodity and the ease of transferring them (19–21). Second, the potential market for LHVs was defined on the basis of the willingness of current HGVs per sector to migrate to LHVs. This assumption takes into account, for instance, that trucks lighter than 20 tonnes will never migrate to LHVs because they could already have made the move to HGV trucks but had not done so. On the basis of this assumption the percentage of conventional trucks ready to migrate is adopted from the Ministerio de Fomento (30). Third, the deviation of each sector is calculated by multiplying the expected load transferred times the number of trucks that can potentially migrate to LHVs. Fourth, a cost reduction (CR) factor was computed to show how far LHVs will reduce costs compared with HGVs by considering the unitary payload weight cost of Spain for both vehicles (39).

TABLE 3 Sector Commodities Analysis and Cost Reduction

Sector Description	Articulated HGVs Type [GVW, Payload (Tonnes)]	Expected Load Transferred (%)	Potential Trucks Migration (%)	Deviation (%)	GTC Cost Reduction, LHVs to HGVs (%)
1. Agriculture, fishing, wood, and cork	Articulated truck (40, 25)	60	33.5	20.1	7
2. Food and kindred products	Articulated truck–refrigerated (40, 24)	80	33.5	26.8	9
3. Nonmetal minerals and kindred products	Articulated truck–bulk tanker (40, 24)	60	33.5	20.1	7
4. Energy, petroleum, and petroleum products	Articulated truck–fuel tanker (40, 27)	0	33.5	0	0
5. Mining	Articulated truck (40, 24)	60	33.5	20.1	7
6. Metal minerals and kindred products	Articulated truck (40, 24)	60	33.5	20.1	7
7. Construction	Articulated truck–bulk tanker (40, 24)	50	33.5	16.75	6
8. Chemical and allied products, paper, edition and kindred products, rubber materials	Articulated truck–fuel tanker (40, 27)	0	33.5	0	0
9. Textiles, clothing, leather and shoes, industrial machinery and equipment, electric and electronic equipment, transportation equipment, and other manufacturing industries	Articulated truck–bulk tanker (40, 24)	50	33.5	16.75	6

NOTE: GVW = gross vehicle weight.

These CR factors are included in the integrated approach to generate the RUBMRIO input according to Equation 6. Other research has established the cost saving of LHV's varying from 10% to 25% against conventional HGVs as a result of greater loads (19, 21).

$$GTC_{ij}^{scenario} = \frac{\left( \sum_{s=1}^9 HGVs_{s,i,j}^{base} \times D_s^{LHV} \times GTC_{ij}^{base} (1 - CR) \right) + \left( \sum_{s=1}^9 HGVs_{s,i,j}^{base} \times (1 - D_s^{LHV}) \times GTC_{ij}^{base} \right)}{\sum_{s=1}^9 HGVs_{s,i,j}^{base}} \quad \forall i, j \quad (6)$$

where

$GTC_{ij}^{scenario}$  = weighted average  $GTC_{ij}$  among regions for LHV's scenario,

$HGVs_{s,i,j}^{base}$  = HGV traffic flows from base case of sector  $s$  and for same O-D pair,

$D_s^{LHV}$  = deviation factors from HGVs to LHV's for each sector  $s$ ,

$GTC_{ij}^{base}$  = GTC in base-case scenario from production or origin region  $i$  to consumer region  $j$ , and

CR = cost reduction factor of LHV's compared with that of HGV's.

The assignment of the LHV scenario was carried out in a way similar to that of the base-case scenario by adopting the calibrated assignment parameters of the base case (VDF parameters and empty trips of trucks per O-D pair). The O-D matrix included additional matrices of trips considering the new user class (LHV's) resulting from the deviation factors applied to the HGV's of each sector. Therefore, it is considered that LHV's will compete with other HGV's in the same road network. Also, for LHV trips the road links that cannot be used by these vehicles were specified. For both scenarios, transfer penalties were defined for each functional classification of roads to prevent very short interchanges, convergence criterion value, and maximum number of iterations to be performed.

## ANALYSIS OF RESULTS

The introduction of LHV's would mean lower transportation costs. This lower cost, in turn, would produce several effects on trade patterns and vehicle flows since it will make sales and purchases easier, and for that reason regions will be able to reallocate goods to other regions, substitute production from other regions, and trade goods that previously were not being traded. All these changes will be reflected in the price of commodities at origin and the road freight transport flows in the network.

The application of the model has assessed both scenarios separately. Initially, the model has allowed the estimate of 2007 data to be taken as the base case considering the  $GTC_{ij}^{base}$  for HGV's exclusively. Then, the  $GTC_{ij}^{scenario}$  was included in the integrated approach to determine the LHV's scenario results, which in comparison with the base case shows the various effects on the CPI and on the transportation system.

TABLE 4 CPI Impacts at the Regional Level

Region Ranking <sup>a</sup>	CPI Analysis		
	Base Case Scenario	LHV's Scenario	CPI Change (%) <sup>b</sup>
<b>Richest</b>			
Madrid <sup>c</sup>	48.523	48.162	-0.744 ♦
Basque Country	42.180	41.836	-0.816 ♦
Navarre	28.002	27.773	-0.818 ♦
Catalonia	79.484	78.904	-0.730 ♦
Aragon	60.851	60.296	-0.912 ♦
La Rioja	23.350	23.237	-0.482 ♦
Balearic Islands	32.775	32.504	-0.828 ♦
Cantabria	32.058	31.825	-0.727 ♦
Castile and Leon	58.399	57.917	-0.825 ♦
Principality of Asturias	32.215	31.925	-0.900 ♦
Galicia	50.907	50.495	-0.808 ♦
Valencia	39.630	39.347	-0.715 ♦
Ceuta and Melilla	16.901	16.773	-0.758 ♦
Canary Islands	27.727	27.529	-0.716 ♦
Murcia	32.960	32.691	-0.814 ♦
Castile La Mancha	47.659	47.283	-0.789 ♦
Andalusia	101.995	100.934	-1.040 ♦
<b>Poorest</b>			
Extremadura <sup>d</sup>	43.069	42.709	-0.834 ♦

<sup>a</sup>Ranked by average gross domestic product (GDP) per capita.

<sup>b</sup>CPI change percentage occurrence symbol = (-0.40 to -0.60) = 1 region;

♦ (-0.60 to -0.80) = 7 regions; ♦ (-0.80 to -1.00) = 9 regions; and

♦ (-1.00 to -1.20) = 1 region.

<sup>c</sup>Of Spain's 18 regions, Madrid is considered the richest.

<sup>d</sup>Of Spain's 18 regions, Extremadura is considered the poorest.

## Impacts on the CPI

The methodology previously outlined enables one to estimate the price ( $P_i^*$ ) for each sector in each region considering both scenarios. Therefore, the impact on the CPI is computed on the basis of the regional data of the consumer basket of goods and services. Table 4 shows both situations by sorting the regions according to average gross domestic product (GDP) per capita.

Results suggest that the prices of commodities decrease for the LHV scenario in all regions. The LHV's scenario is expected to reduce the CPI by between -0.48% and -1.04%, depending on the region. If the price reduction is passed on to consumers, they will feel some slight relief in their pocketbooks.

The effects will be experienced in a different way in each region because the quantities of items in their market baskets differ. For example, the results have registered a large decrease in Andalusia (-1.04%), while most of the regions (16 of 18) have registered decreases in a range between -0.60% and -0.80%. Also, results show that the regions will be affected regardless of their relative wealth. With regard to geographic location, the results offer evidence that this is not a conclusive factor. For example, regions that occupy a peripheral position, such as Andalusia, Extremadura, and Galicia, taking Madrid as the center, are expected to experience significant reductions in prices, but this also happens in central regions such as Madrid. Peripheral regions will become more competitive, so they will be able to increase exports and imports and benefit from agglomeration effects.

## Impacts on Transportation System

Impacts on the transportation system have been focused on changes in flow volumes and pollutant emissions under each scenario, as



TABLE 5 Transportation System Impacts by Flow Volumes

Functional Classification Class	Number of Links (km)	Total AADT Assigned HGVs/day <sup>a</sup> (millions)			HGVs-km/day (millions)			Payload-Distance (tonne-km/day) (millions)		
		Base-Case Scenario	LHVs Scenario	Change (%)	Base-Case Scenario	LHVs Scenario	Change (%)	Base-Case Scenario	Road Upgrade Scenario	Change (%)
1. Talled highways	604 (2,703)	1.78	1.76	-1.39	7.73	7.61	-1.62	92.77	96.03	3.51
2. Free highways	1,739 (8,122)	6.59	6.34	-3.86	29.28	28.17	-3.79	351.41	352.10	0.20
3. National road system	1,531 (6,597)	1.68	1.59	-4.95	6.91	6.57	-4.92	82.90	78.82	-4.92
All	3,874 (17,422)	10.05	9.69	-3.60	43.92	42.35	-3.59	527.08	526.96	-0.02

<sup>a</sup>Column lists the total annual average daily traffic (AADT) value of HGVs assigned per day, measured in millions.

TABLE 6 Transportation System Impacts by Emissions

Functional Classification Class	Number of Links (km)	CO <sub>2</sub> Emissions (tonnes/day)			NO <sub>x</sub> Emissions (tonnes/day)			PM <sub>10</sub> Emissions (tonnes/day)		
		Base-Case Scenario	LHVs Scenario	Change (%)	Base-Case Scenario	LHVs Scenario	Change (%)	Base-Case Scenario	LHVs Scenario	Change (%)
1. Talled highways	604 (2,703)	7,465	7,648	2.45	196.6	201.4	2.45	6.5	6.7	2.51
2. Free highways	1,739 (8,122)	28,277	28,098	-0.63	744.6	739.6	-0.63	24.7	24.6	-0.58
3. National road system	1,531 (6,597)	6,671	6,343	-4.92	175.7	167.0	-4.92	5.8	5.54	-4.92
All	3,874 (17,422)	42,413	42,174	-0.77	1,117	1,108	-0.77	37.1	36.8	-0.72

NOTE: CO<sub>2</sub> = carbon dioxide; NO<sub>x</sub> = oxides of nitrogen; PM<sub>10</sub> = particulate matter up to 10 micrometers in size.

shown in Tables 5 and 6. Overall, results show a promising decrease of freight transport flows and emissions (-3.60% and -0.77%, respectively). However, the detailed results sorted by type of road are worth analyzing.

The reduction in the total annual average daily traffic experienced by the national road system is the greatest compared with the remaining types of roads. The explanation for this notable reduction is that LHVs are not allowed to travel on national roads. However, the study of payload distance reveals that in the LHVs scenario, tolled and free highways will transport more tonnes using fewer vehicles than before. This result is explained by the greater carrying capacity of LHVs compared with HGVs, and the national road constraint.

The disaggregated results per link (Figure 3a) also show important variations over the network. For example, 1,482 km (8.5%) would increase flows (explained by LHVs' constraints on using national roads), whereas the remaining 15,940 km (91.5%) would decrease flows. These results show that the introduction of LHVs would relieve traffic in Spain's road network. Figure 3b shows the flow volumes of LHVs in each link. Seventy-one percent of the high-capacity network will have fewer than 500 LHVs per day, 27% will have between 500 and 1,000 LHVs per day, and only 2% will have more than 1,000 LHVs per day.

## CONCLUSIONS

Results demonstrate that the integrated approach applied in this study, based on a mesoeconomic model, is able to forecast how the implementation of transport policy measures may determine direct and indirect effects on the economy and transportation flows. The introduction of LHVs has several effects because importing and exporting goods between regions will be cheaper and easier. The

effect will be the result of a set of complex relationships depending on the characteristics of the region, such as its location in the country, its consumption patterns, and its economic structure. Overall, the introduction of LHVs will lead to CPI reduction.

In regard to transportation flows, the following trends may be expected to occur. First, a substantial reduction of the freight transport services may be expected because LHVs will reduce the amount of truck kilometers needed for transporting goods. Second, national roads will experience the greatest decrease in traffic flows and payload distances (tonne-kilometer). Third, tolled and free highways will experience a slight decrease in their traffic flows (truck kilometers), but they will move greater tonne-kilometer flows.

In regard to pollutants, emissions will decrease in the LHVs scenario. However, tolled highways will produce more emissions (carbon dioxide), oxides of nitrogen, and particulate matter up to 10 micrometers in size since LHV emissions factors per kilometer are greater than the emissions factors of HGVs.

Overall, the results have pointed out that the present modeling approach based on a commodity-based structure allows for estimating the impact of transport policy measures on freight flows running on the road transportation network. This approach overcomes the undesirable limitations of models based on truck trips.

The integrated approach has shown interactions between the economic sectors and the regions of Spain. Each region experiences a different substitution and generative effect of trade. Although there are recognized limitations, the integrated approach has provided a novel methodology for investigating the role of transportation policy on the economy and for studying the impact on the performance of the transportation system. As a result, this research has proposed and constructed a comprehensive approach to better forecast economic and transportation impacts on the introduction of new freight transport vehicles (in this case, LHVs) in a country such as Spain.

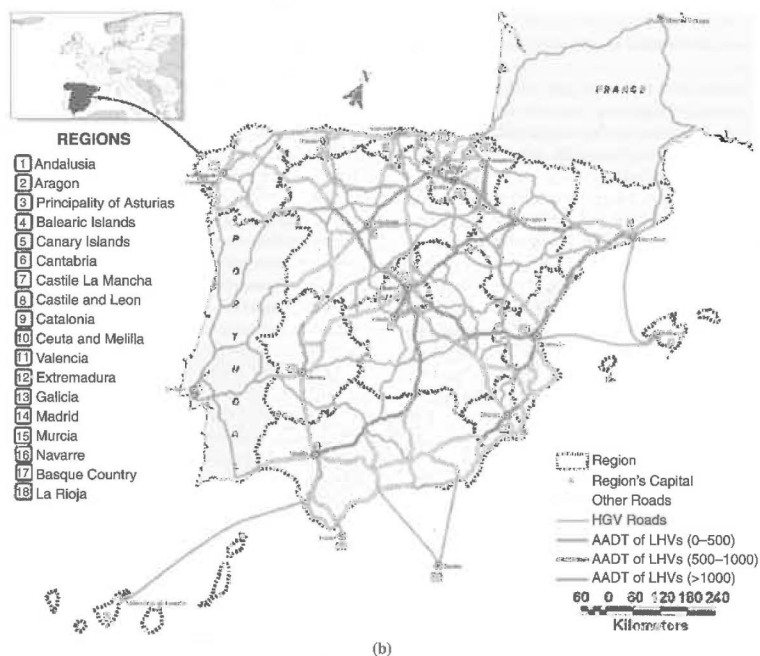
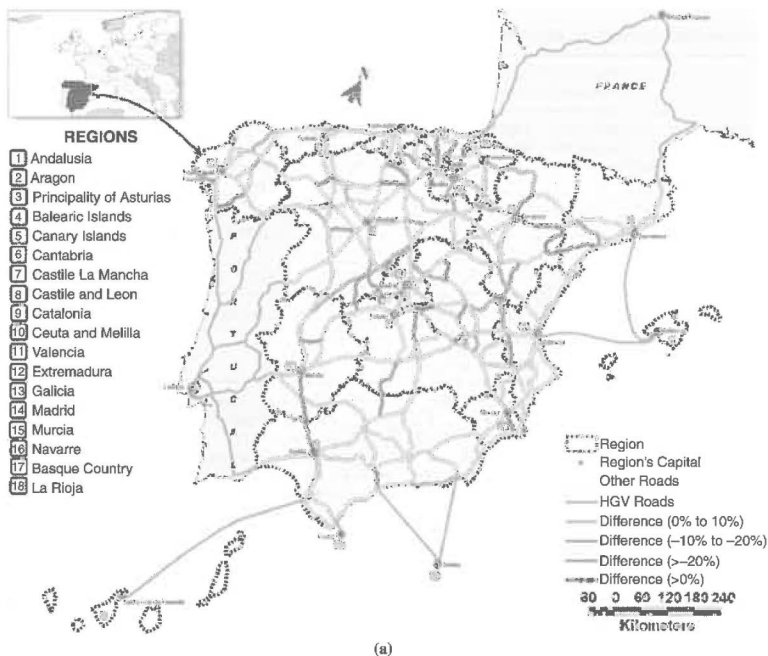


FIGURE 3 Transportation system impacts in LHV scenario: (a) AADT change (%) and (b) AADT of LHVs (LHVs per day).

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